

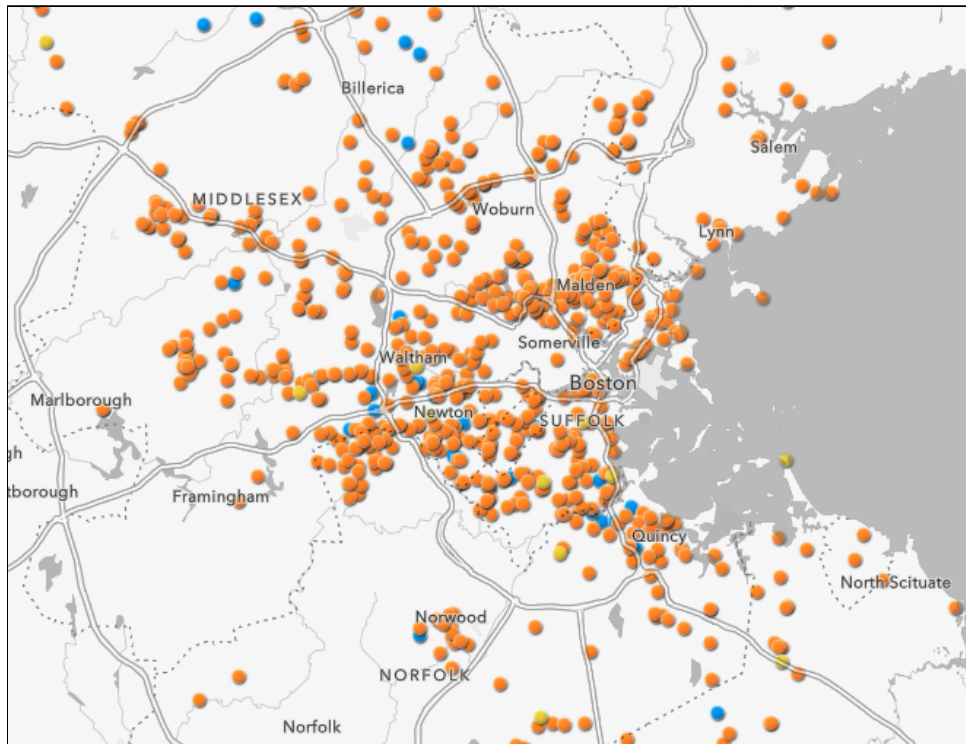


Significant Environmental Impact (SEI) Natural Gas Leaks

Shared Action Plan Year 1 (2019/2020)

Utilities Enacting the Leak Extent Method

April 27th 2021



Utility reported SEIs as of 9.30.2020

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Executive Summary

Massachusetts has the second oldest natural gas infrastructure in the country. Old pipes leak methane, a greenhouse gas 86 times more potent than carbon dioxide over the first 20 years in the atmosphere.¹

The amount of gas leaked annually from the Commonwealth's aging gas distribution system is equivalent to 40% of the emissions of all of the state's stores and businesses combined.² The cost of this wasted gas is passed on to the customers, estimated to be over \$11 million per year.³ In addition to polluting the air, methane suffocates street trees as it seeps into their root zones, depriving them of oxygen.



Old gas pipes

Research by Boston University and Gas Safety Inc. in 2016 showed that just 7% of the greater Boston distribution system leaks emit half of all the gas by volume, creating a clear policy opportunity.⁴ Later the same year, the Massachusetts Legislature enacted a law requiring that these leaks of significant environmental impact (SEIs) be repaired, since doing so would cut methane emissions in half for the least cost to the utilities and the least disruption to cities and towns.

However, given that gas companies had always been mandated to focus on the explosive potential of a leak and not emissions, they had no reliable and accurate method to identify these largest leaks that have a significant environmental impact. In 2017, HEET coordinated a large collaborative study working with Columbia Gas MA, Eversource Gas, and National Grid Gas, together with Gas Safety Inc., Mothers Out Front and other stakeholders. This research team field tested multiple methods and found the leak extent method⁵ was a quick, effective and low cost solution.⁶

This report documents the progress of this first-in-the-nation program and reports on the use of this new identification protocol - the leak extent method⁷ - to identify and repair SEIs in the 2019 dig season in Columbia Gas, Eversource Gas, and National Grid Gas territories. HEET independently verified the results, with Gas Safety Inc. and provided analysis.

Massachusetts is the first to enact legislation to identify environmentally significant leaks, the first to determine an SEI protocol, and the first to test it widely in the field across multiple gas companies. We hope to report in coming years that we are also first in the nation to cut in half our methane emissions from the gas distribution system.

¹ IPCC Climate Change Report, "Climate Change 2013: The Physical Science Basis," Table 8.7

² See page 5

³ See Appendix 4, Annual Total Cost from the Distribution System for more information. Reference is calculated using findings from McKain et al, [Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts](#)

⁴ Hendrick et al, "[Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments](#)"

⁵ Originally suggested by Bob Ackley of Gas Safety Inc. - see Appendix 2

⁶ Magavi, Z., Ackley, R., Hendrick, M., Salgado, E., Schulman, A., Phillips, N., "A Method of Identifying Large Volume Leaks in Natural Gas Distribution Systems", publication pending.

⁷ See Appendix 2

Shared Action Plan Year 1 Findings at a Glance

- Gas company's reported use of the leak extent method significantly increased.
- Whilst gas companies continued to use the leak extent method to identify SEIs in the field, they appeared to be over-reporting the actual number of SEIs, and reporting larger leak extents than the real extents, potentially because the protocol is still new.
- Columbia Gas and Eversource found lower rates of SEIs than in previous years, possibly due to these utilities having begun to identify and repair their SEIs in 2018, before the regulation was formally enacted. Should this prove true, we recommend utilities continue using the leak extent method to measure leaks, whilst adjusting the SEI definition threshold to continue to capture the largest 7% of leaks.
- SEI repairs continue to appear to be successful only 1/3rd of the time. Improving this repair rate will save money, emissions and work hours.
- We didn't see the correlation we expected between FluxBar⁸ steady state flux and leak extent and will continue to study this relationship.
- The cavity ringdown spectrometer continues to be an excellent tool for finding new potential gas leaks.

Pipeline and Hazardous Materials Safety Administration (PHMSA) TAG Project Findings at a Glance

- SEI leak extent size was not a predictor of SEI leak extent growth rate.
- SEI grade 3 leaks evolved in terms of hazard potential at a similar rate to non-SEI Grade 3 leaks, with about 13% of both categories becoming grades 2 or 1.
- SEIs were found predominantly on low pressure 6" cast iron pipes installed before 1930 and intermediate pressure 2" coated steel pipes installed after 1930. Given that the same size hole on an intermediate pressure pipe will leak gas at a faster rate than one on a low pressure pipe, prioritizing leaks on intermediate pressure 2" coated steel pipes may be an effective method of cutting emissions rapidly.

See [Appendix 6](#) for more information about the PHMSA TAG project.

⁸ See [FluxBar Adoption and Use](#)

HEET is a nimble nonprofit that convenes and generates expertise, research, and ideas to drive a swift and just transition off fossil fuels. Our outsized impact is created through leading large networks of diverse stakeholders to enable information and ideas to emerge.

HEET verified⁹, analyzed and wrote up the information in this report. To maintain its independence, HEET has never taken money from a gas company. HEET is funded by foundations and individual donors.



HEET testing the FluxBar

Gas Safety Inc. has over 40 years of professional experience with gas and gas leaks and six peer-reviewed scientific publications¹⁰. The 'leak extent' protocol tested in the Large Volume Leak Study was initially proposed by Gas Safety Inc.

The Gas Leaks Allies is a coalition of more than 25 organizations and researchers focused on reducing methane emissions from the natural gas distribution system in Massachusetts while transitioning to fossil-free energy sources. This unconventional, interdisciplinary collaboration of scientists, gas experts, activists, and concerned citizens is finding solutions for the problems caused by aging, leaking pipes buried in our neighborhoods.

⁹ Gas Safety Inc. was contracted by HEET to provide professional gas surveying third-party verification

¹⁰ <http://gassafetyusa.com/resources/>

Background

Gas Leaks Accelerate Climate Change

Pipe-quality natural gas is over 90% methane. If leaked to the atmosphere without being burned, it remains methane, a remarkably potent greenhouse gas, much more destructive to the climate than if the gas is burned and transformed to carbon dioxide. Because of the potency of methane, if a total of 3% or more of it is leaked unburned into the atmosphere anywhere from wellhead to point of use, its impact on the climate is worse than burning coal.¹¹ A NASA study in 2019¹² found that natural gas associated methane emissions are spiking globally in the atmosphere.

Research conducted by Harvard University and Boston University¹³ in 2015 measured the amount of both methane and ethane (a chemical marker found only in natural gas) in the atmosphere over Greater Boston. From the results, the researchers calculated that approximately 2.7% of the total natural gas being transported into the Greater Boston area was leaked unburned to the atmosphere, instead of being used as an energy source.



Thermal imaging of gas emitting from a sewer

The estimated impact of super-emitting leaks is equivalent to 4% of the carbon dioxide emissions in the state, or the emissions of 40% of all our state's stores and businesses (i.e. the commercial sector) in 2017.¹⁴

7% of Leaks Emit Half of All the Gas

Research conducted by Boston University¹⁵ in 2016 found that in Greater Boston just 7% of the leaks on the pipes under the streets in the distribution system emit fully half of all the gas by volume. These leaks are called super-emitting leaks. Scientific research has duplicated this relationship from wellhead to distribution system, showing that a small fraction of the leaks are responsible for half the emissions.¹⁶ Since the cost of the wasted gas is passed onto the customers, this also represents wasted money.

If “super emitting” leaks could be identified and repaired, the state could cut emissions and wasted money for the least cost and the least disruption

¹¹ Robert W. Howarth, “[A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas](#)”

¹² Worden, J.R. et al., “[Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget](#)”

¹³ McKain et al, 2015, “[Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts](#)”

¹⁴ See Appendix 7

¹⁵ Hendrick et al. 2016, “[Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments](#)”

¹⁶ Brandt et al, 2016, “[Methane Leaks from Natural Gas Systems Follow Extreme Distributions](#)”



Grading of Gas Leaks

Methane gas is explosive when it builds up to between 5% and 15% of the ambient air in any space. Leak grading has historically focused on this.

Grade 1(hazardous): Any leak in or near a contained space, such as a building or manhole, that could explode. Grade 1 leaks are fixed immediately.

Grade 2 (potentially hazardous): Any leak that could become a Grade 1 – close to a building, etc. Grade 2 leaks are monitored and fixed within 12 months.

Grade 3 (non-hazardous): All other leaks, those that are not close to buildings or in contained spaces. A Grade 3 leak in the middle of the street for instance could be leaking an enormous quantity of gas. Before the SEI law, there was no requirement that high emitting leaks like this be fixed by the gas company and some leaked for decades.

Significant Environmental Impact Law Passed in 2016

In 2016, the Gas Leak Allies, a coalition of over 25 nonprofits and researchers working to reduce emissions, worked to develop and pass new legislation¹⁷ requiring that these super-emitting gas leaks of “significant environmental impact” (SEI) must be repaired. Grassroots mobilization by Mothers Out Front was a driving force in this effort.

Unfortunately, with the concept of super-emitting leaks so new, *the gas companies had no proven method to identify which of the over 17,500¹⁸ unrepaired leaks in the state were emitting the most.*

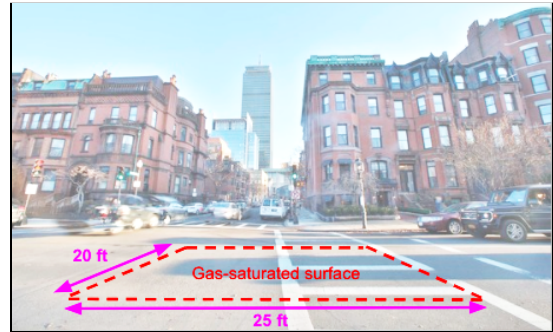
¹⁷ “[Section 144, The 191st General Court of the Commonwealth of Massachusetts](#)”,

¹⁸ Report on the Prevalence of Natural Gas Leaks in the Natural Gas System, DPU 17-GLR-01

The 2017 Large Volume Leak Study

In response, in 2017 HEET coordinated the “Large Volume Leak Study”, working with Columbia Gas MA, Eversource Gas, and National Grid Gas, as well as with Gas Safety Inc., Mothers Out Front and other stakeholders.^{19,20}

The study measured leak emissions using the chamber method, a peer reviewed method for measuring emissions over time, and then tested five proposed proxy methods for identifying the largest volume leaks quickly in the field. Gas workers worked together with grassroots volunteers and scientists to collect the data on leaks across the state.



Key Findings of the 2017 Large Volume Leak Study

The study concluded that the leak extent method was the fastest and most reliable proxy method for identifying high emitting leaks. This method classifies a leak with a gas-saturated surface area larger than 2,000 ft² as emitting enough gas to be considered a leak with a significant environmental impact (SEI).

The study found the emissions of a leak are strongly correlated ($n=67$, $R^2=0.86$) with the leak extent, or size of the gas-saturated surface area over the leak. The bigger the leak, the greater the emissions.

One of the alternate methods tested was the “barhole method.” The barhole method involves making a hole in the ground using a handheld bangbar and inserting a combustible gas indicator in the hole. According to the method, any leak with any sub-surface reading over 50% gas would be considered an SEI leak. However, the study found no correlation ($n=68$, $R^2=0.008$) between the emissions of a leak and a barhole subsurface reading of over 50%. In addition, National Grid trained gas personnel returned to their studied leaks using the same equipment at the same location and were unable to replicate the barhole readings, showing no correlation between past and present barhole method results.

Shared Action Plan

Based on the outcomes of the Large Volume Leak Study, in October 2017, HEET, Columbia Gas, Eversource, and National Grid created a five-year “Shared Action Plan” ([Appendix 3](#)). The three gas companies and HEET submitted comments jointly to the Massachusetts Department of Public Utilities (DPU) with the request that the leak extent method and the Shared Action Plan be enacted as regulation.

The Shared Action Plan detailed that:

¹⁹ Magavi, Z. “Identifying and Rank-Ordering Large Volume Leaks in the Underground

Natural Gas Distribution System of Massachusetts”, 2018. <https://dash.harvard.edu/handle/1/37945149>

²⁰ Magavi, Z., Ackley, R., Hendrick, M., Salgado, E., Schulman, A., Phillips, N., “A Method of Identifying Large Volume Leaks in Natural Gas Distribution Systems”, publication pending.

- The leak extent method would be used by the gas companies to identify SEI leaks, until or unless replaced by a superior method.
- These SEIs would be fixed faster than the DPU had initially suggested.²¹
- There would be data transparency, independent verification of the results coordinated by HEET, and annual reassessment of data to iterate and refine methods.



SEI Enactment

The Massachusetts Department of Public Utilities (DPU) issued the SEI regulation March 8, 2019. Before that date, the gas utilities have not been allowed to submit for reimbursement of SEI repair expenses. In spite of this uncertainty of reimbursement, for the 2018 field trial year, the gas companies identified 212 SEIs and performed repairs on 19 of those, honoring the Shared Action Plan.

In enacting this regulation, the Department of Public Utilities led the nation in prioritizing SEIs and in defining an effective procedure, leak extent, for their identification. Use of the leak extent method will save money for customers, reduce emissions, and potentially cut the equivalent of 4% of the state's greenhouse gas emissions inventory in as little as three years.

Unfortunately, the department also allowed gas companies to use the "barhole method," a method which the 2017 study found did not work at all. No matter which method the gas companies use to identify the SEIs, they will get paid more for repairing them. It is in everyone's best interest for the gas companies to continue to use the effective leak extent method to save money and emissions.

SEIs Are Worth Repairing, Both for the Climate and for the Wallet

The Applied Economics Clinic (AEC) created a top-down analysis on the likely return on investment of SEI repairs. As a top-down estimate, it represents the upper range of potentially wasted money and emissions. A bottom-up measurement of emissions would give a lower boundary to the potential range. An accurate bottom-up direct emissions measurement of SEIs would require a larger scale emissions study with many more leaks surveyed than has been done to date.

AEC used the findings of the 2016 Harvard University / Boston University study²² to calculate the amount of gas lost into the atmosphere.²³ AEC assumed that just a third of that lost gas came from the distribution system (with the rest coming from inside buildings, LNG tanks, etc.) and multiplied that amount by the marginal cost of gas to get the total cost of the wasted gas.

Super-emitting leaks (7% of the total leak population) are responsible for half of the leaked gas from our distribution system. The remaining 93% of the leaks emit the rest of the gas. With this information AEC calculated the amount of gas lost per super-emitter and gas lost per average leak. While the exact quantity of gas is estimated and varies over time, the relationship or ratio

²¹ ["Uniform Natural Gas Leaks Classification"](#)

²² McKain et al, 2015, ["Methane emissions from natural gas infrastructure and use in the urban region of Boston"](#)

²³ The Energy Information Administration report that year stated a smaller amount of lost gas in Massachusetts (1.9%); https://www.eia.gov/naturalgas/annual/pdf/table_a01.pdf

should hold true and indicate the relative savings of repairing large leaks first.

The average cost of a leak repair was calculated using the total cost of repairing all the leaks across the state divided by the total number of leaks remaining (both cost and number of leaks as reported by the gas companies).

SEI leaks are identified using a proxy method (the leak extent) that is easy and reliable, but not perfect; therefore the leaks identified are a slightly larger percentage of the leak population (~10%). The table below shows the results. Fixing an average SEI leak gives consumers a return on investment, with the given assumptions and approach, in approximately 14 months. This means the payback for an SEI repair is nine times faster than for a non-SEI repair.

	Total gas lost/year (therms)	Number of leaks	Gas lost per leak/year (therms)	Cost of lost gas/year	Return on Investment (years)
Average leaks	37,753,544	17,810	2,120	\$633	6.2
Super-emitter leaks	18,876,772	1,186	15,915	\$4,752	0.8
Grade 3 leaks <u>excluding</u> super-emitters	18,876,772	15,758	1,198	\$358	11
SEIs	20,009,378	1,781	11,235	\$3,355	1.2

The Shared Action Plan 2018-2019 SEI Field Trial

A field trial year of the shared action plan work began in 2018. Key findings are summarized below and the full report can be found [here](#).

- Gas companies were able to use the leak extent method to identify SEIs in the field. The measurements of individual leaks were relatively consistent over a work season, even when measured by different personnel from different organizations with varying weather conditions.
- A top-down analysis showed a fast 14-month return on investment for repairing SEIs.
- All three gas companies appeared to be under-identifying some SEIs, potentially because the protocol was new. A mobile CRDS (cavity ring-down spectrometer) survey also showed promise in identifying SEIs.
- The FluxBar, a tool for comparing and confirming the emissions of leaks through a proxy measure of flux, needed more data in 2019 to determine efficacy and refine the protocol.
- Leak repairs didn't appear to always be successful and the success rate needed to be further evaluated to maximize emissions savings per dollar.
- There was potential for refinement of the leak extent method, requiring more information sharing.

Shared Action Plan Year 1 (2019-2020) Results

Utilities including Columbia Gas, Eversource Gas and National Grid all reported using the leak extent method²⁴ to successfully identify SEIs. HEET worked with Gas Safety Inc to perform independent verification and repair surveying of a random sampling of the utility-reported SEIs. This program is a first-in-the nation model, indicating that gas distribution companies can successfully identify and repair the gas leaks that emit the most methane in order to cut emissions most efficiently.

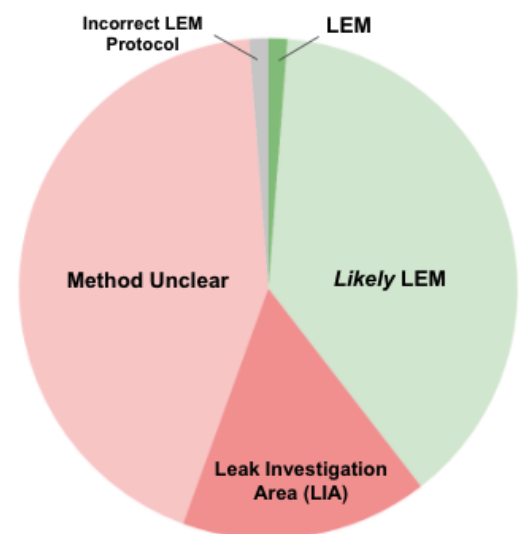
Leak Extent Method Adoption Increased

In 2019 National Grid were able to share leaks they reportedly measured using the leak extent method. In total, 734 SEIs across all three utilities were shared with HEET to check and ensure that the leak extent method was consistently working well. This was a 12-times increase in sharing compared to the trial year before. This year 95% of the shared data was from National Grid.

Use of the Leak Extent Method Needs to Improve

Using the leak extent method, HEET independently surveyed 159 reported SEIs (124 from National Grid, 33 from Columbia Gas, and 2 from Eversource). We found that both National Grid and Columbia were over-identifying SEIs - only half of National Grid's SEIs and a third of Columbia Gas SEIs were confirmed by HEET to be SEIs (the Eversource leaks were repaired by the time we surveyed them). In addition to *over-identification*, both National Grid and Columbia Gas appeared to be *over-measuring* SEI leak extents by 5 times and 2 times respectively.

In an effort to better understand this, HEET meticulously analyzed 81 National Grid leak surveys which were kindly shared with us. These surveys were created - and even represented - by National Grid and its contractors, Omark, USIC and Recon. We found that only about 40% of the surveys were *likely* performed using the leak extent method, with only one *definitely* performed using the leak extent method. However, for another 40% of the leaks, we were surprised to find that it wasn't clear from the survey reports how the leak extents had been calculated. Also, another 15% of the surveyors confused leak extents with the larger leak investigation area. We also found that there was also no clear increase in the leak extent method efficacy over time. Finally, data transcription errors were found between the surveys and the data shared with us 25% of the time,



²⁴ See [Appendix 2](#)

including incorrect leak extents, addresses and survey dates.

Based on these findings, HEET made recommendations to National Grid to improve leak extent method adoption and efficacy. Most importantly these recommendations included :

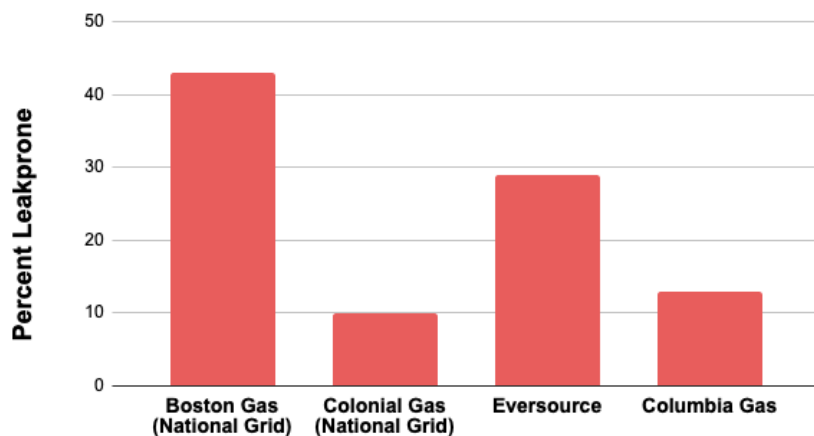
1. HEET met with surveyors to better understand how they are measuring and calculating leak extents
2. Make simple yet important improvements to the survey reporting protocol including :
 - a. Clearly draw in leak extent dimensions
 - b. Include a log of all the measurements in the survey
 - c. Take all measurements from the same reference point to allow leak extent verification from the survey itself
3. Increase leak extent method education of surveyors and surveyor trainers

HEET remains ready to meet with surveyors to assist through observation and training. HEET's assistance is free to gas utilities, including National Grid and their subcontractors, and can potentially help utilities reduce emissions.

Were Any SEIs Missed?

The aging infrastructure in Massachusetts is not evenly distributed across the state or within any one gas distribution company. This must be taken into account when evaluating results based on the subset of leaks studied here, which were nearly all in National Grid territory.

The chart on the right shows the percent of leakprone infrastructure for the largest Massachusetts gas utilities. Leakprone infrastructure has historically referred to non-cathodically protected steel, cast iron and wrought iron pipes. According to D.P.U. 20-GLR-01, '*Report to the legislature on the prevalence of natural gas leaks in the natural gas system*', National Grid is now including pre-1985 plastic/Aldyl-A as leakprone, which was 3% of their system in 2020.



Source : Report to the Legislature (D.P.U 20-GLR-01), 2020

Based on research, we were expecting SEIs to account for 7-10% of all grade 3 leaks. Based on the extensive leaks database that was shared with HEET, National Grid had a higher than expected SEIs rate of 24% (98 SEIs out of 407 grade 3 leaks in total). Taking into account that their use of leak extent method appeared to be over-identifying SEIs by a factor of 2, this SEI rate might reasonably be closer to 12%.

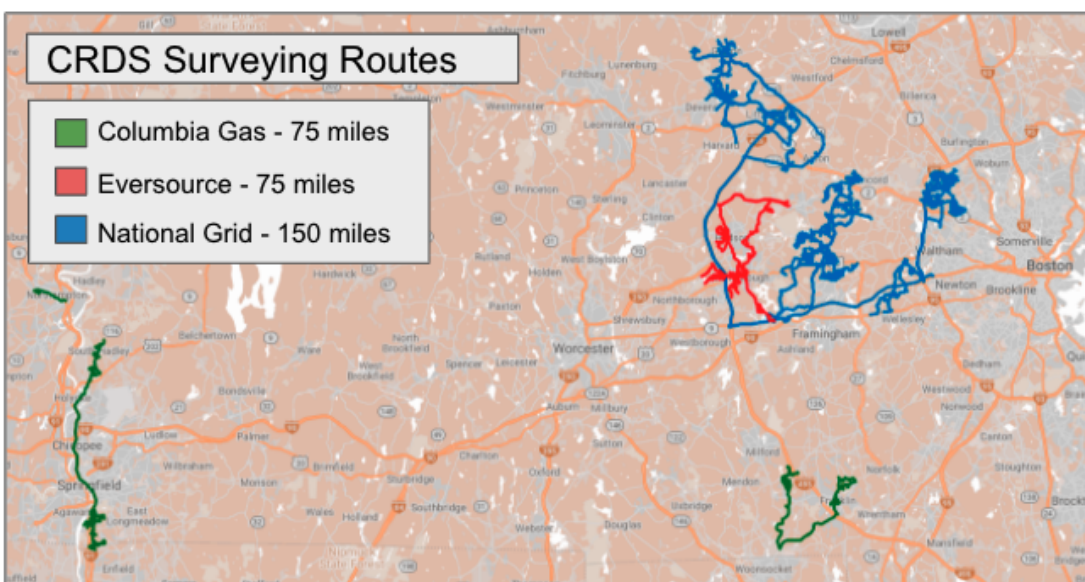
Based on data reported in the quarterly leak inventory reports submitted to the DPU, Columbia Gas had a lower than expected SEI rate of 4% (27 SEIs out of 643 grade 3 leaks in total), and Eversource 2% (9 SEIs out of 422 grade 3 leaks in total). The Columbia Gas SEI rate might be closer to 1% when taking into account that their use of the leak extent method appeared to also be over-identifying SEIs by a factor of 3.

Based on the population of leaks in the Large Volume Leaks study, leaks 2,000 ft² or larger accounted for approximately 50% of all of the emissions from that studied leak population. However, over time as SEIs are repaired, the population of leaks changes, and SEIs might now require a different threshold. This might explain the Columbia Gas and Eversource lower SEI rates.

We recommend utilities continue using the leak extent method to measure leaks, whilst expanding the SEI grade to include the 7% of leaks with the largest leak extent. This approach will continue to capture half of the total emissions no matter the population of leaks. A given gas utility could define SEIs in their territory as the top 7% of their leak extents to ensure they are optimizing their methane emissions reduction. Alternatively, the leak extent threshold could be set annually based on the prior year's aggregated set of all grade 3 leak extents across gas territories, which would ensure that the state is cutting methane emissions from pipeline gas leaks in half.

Searching for Missed SEIs

In November 2019, Gas Safety Inc. surveyed 300 miles of roads covering 18 towns with the Picarro CRDS in areas that the utilities had already surveyed for SEIs. We surveyed 150 miles of National Grid territory and 75 miles in both Columbia Gas and Eversource territories.





A Picarro CRDS Natural Gas Analyzer



The Picarro CRDS installed in the car

As the car is driven, a sensor detects parts per million of methane and records the amounts found together with GPS coordinates. This CRDS is similar to the CRDS that EDF uses in its mobile surveys.



Gas leaks in Lexington, MA

The Picarro data can be visualized in Google Earth maps. The red lines show where the car drove; the peaks show where methane was found.

CRDS Found New Additional SEIs

We found numerous new CRDS elevated methane locations (potential leaks) which did not correspond to reported unrepaired leaks. In total, we found 325 new potential leaks which did not correspond to any of the 479 reported unrepaired leaks on our route.

Utility	Reported unrepaired leaks on route	New potential leaks
Columbia	38	41
Eversource	50	44
National Grid	391	240
Total	479	325

The possible reasons for these new potential leaks include:

- Not all unrepaired leaks were included in the 2019 annual service quality report
- Partially repaired leaks were being categorized as completely repaired
- New gas leaks had developed since the area was last surveyed
- Rarely, elevated CRDS methane readings may come from landfills, sewers, septic, ruminant and swamps

A subset of the larger potential leaks were surveyed and found to be new SEIs that were not yet reported by the utilities. This included 6 new SEIs for National Grid and 1 new SEI for Eversource. No new SEIs were found on the route in Columbia Gas territory. We did not have

the resources to survey all of the new potential leaks. See [Appendix 5](#) - CRDS Analysis Methods for more details on how this analysis was performed.

The CRDS Detected Already Identified Leaks

On average, 60% of the time, the CRDS located elevated methane at locations of reported unrepaired leaks.

Utility	Reported unrepaired leaks on route	CRDS matches	CRDS rate of correspondence
Columbia	38	24	63%
Eversource	50	30	60%
National Grid	391	222	57%
Total	479	275	Average: 60%

The possible reasons for this lower correspondence rate include :

- Some reported unrepaired leaks were repaired between date of data reporting and date of our survey.
- Some reported unrepaired leaks were not detected due to being too small and too far away from the road. Whilst the CRDS is extremely sensitive (measuring parts per billion of methane), given the right wind conditions, small distant leaks - particularly service line leaks - may not be detected.

CRDS Summary

In order to develop a complete picture and make conclusions about CRDS effectiveness, we would need to survey all reported unrepaired and repaired leaks, and all additionally found elevated methane locations (new potential leaks). We were not able to do this during this project due to time and resource constraints. However, the implications of finding so many new potential leaks using the CRDS cannot be overstated. We propose that a larger study be conducted to survey unrepaired, repaired and new potential leaks to develop a more conclusive understanding of the effectiveness of the CRDS system. Especially during winter patrol, the CRDS could allow more frequent surveys, increasing the safety for all.

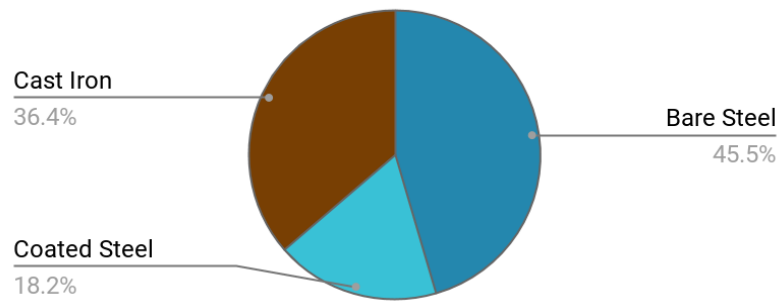
Where Do SEIs Occur ?

Our hope is that as we learn about SEIs in terms of their tendency to appear on different types of pipe materials or different amounts of pipe pressure, we might be able to refine the leak extent method to help the gas companies prioritize the areas most likely to have SEIs.

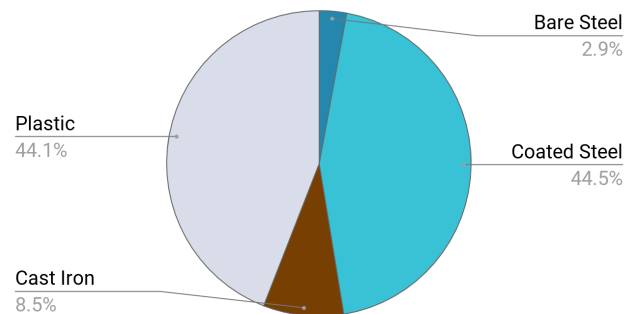
We had information about the pipe material only for 34 Columbia Gas leaks, of which 11 were verified SEIs. We didn't have material information for the National Grid or Eversource leaks. We found that the 11 SEIs mostly occurred on 4" higher pressure steel pipe.

Distribution of HEET Verified SEIs by Pipe Material

Bare steel and cast iron pipes appeared to be more likely to develop SEIs, especially when compared to the material distribution of the Columbia Gas territory below. This is consistent with our understanding of where most leaks in general are occurring. More data is needed to confirm this tendency since this was a very small dataset.



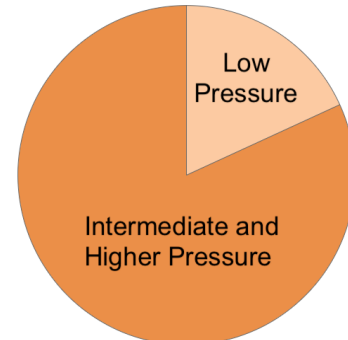
There were no SEIs reported or verified on plastic pipes. Columbia Gas territory as a whole has over 44% plastic pipes. This suggests that plastic pipes are less likely to develop SEIs.



2019 Columbia Gas System Enhancement Plan/Pipe Materials for All of Eversource Territory (Source: D.P.U. 19-GSEP-05 table II-1)

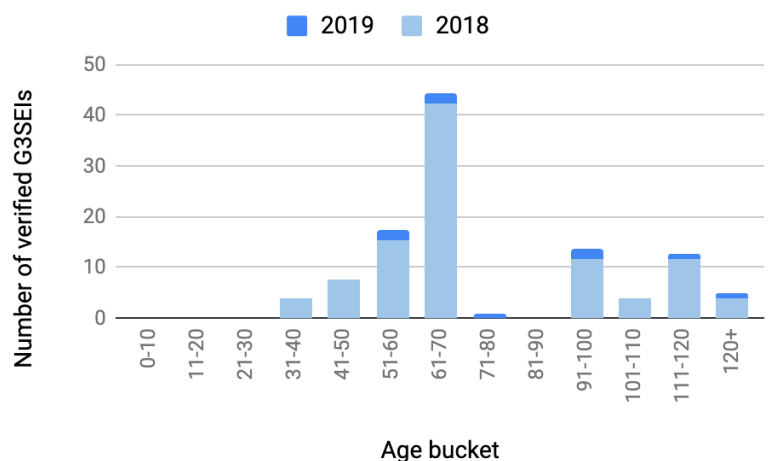
Distribution of HEET Verified SEIs By Pressure

We examined the distribution of the 11 SEIs by pipe pressure. Less than 20% occurred on low pressure pipes. We did not have information on pipe pressure across the entire Columbia Gas territory to use as a reference and give this result more meaning.



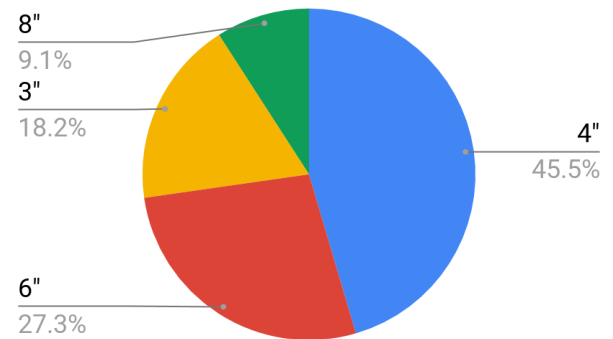
Distribution of HEET Verified SEIs By Age of Pipe

We examined the distribution of the 9 of the 11 SEIs by the age of the pipe installation and found it to build on last year's pattern. We did not have information on ages of pipes across the entire Columbia Gas territory to compare this with. The median age was 75 and the average age was 83. We suggest that the gap in the 71-91 years old range is possibly due to no new pipes being installed because of World War II, and the spike around 60 years old is possibly due to a building boom leading to an increase in the number of pipes being installed at that time.



Distribution of HEET Verified SEIs By Pipe Diameter

We examined the distribution of these 11 verified SEIs by pipe diameter and found they most commonly occurred on 4" pipe.



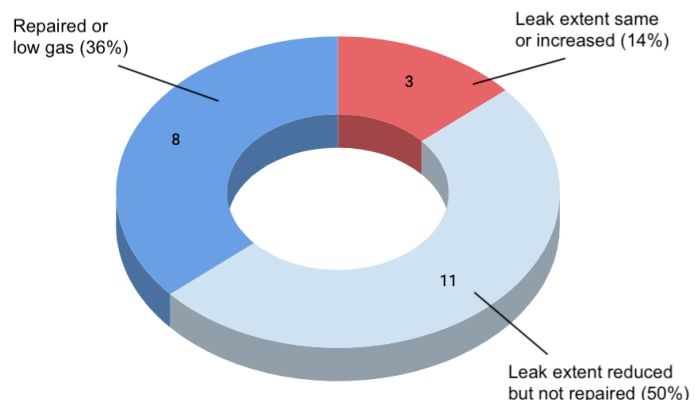
Other Related Findings

In 2019, HEET was awarded a PHMSA grant to explore SEIs further. This more extensive study followed 100 verified SEIs across 4 seasons, and included a similar analysis of what conditions fostered SEIs. Across these SEIs, two most commonly occurring types of G3SEIs appeared to emerge - those on low pressure 6" cast iron pipe installed before 1930, and those on intermediate pressure 2" coated steel pipe installed after 1930. The large volume leak study indicated that leaks with higher leak flux were on pipes with higher gas pressure, and we recommend prioritizing the intermediate steel category over the cast iron category.

Success Rate of Verified SEIs Repairs

Of the 159 leaks we surveyed, 29 leaks were reported repaired by the utilities. To allow all residual gas to leave the soil in the area, HEET returned to 27 of these leaks, 22 of which were verified SEIs, at least a month after repair to check for the presence of gas. If there was any, we recorded if the leak extent was smaller, the same, or larger. Whilst this data set is too small to be conclusive, the results follow a concerning trend from the trial year and the large volume leak study where only 1/3rd of the leaks are fixed by repair

work. The PHMSA funded study also included a repair rate analysis of 25 different verified SEIs and also found that only 1/3rd of these were actually fixed after repair work.



The repair crews are careful and effective and we have observed that they are repairing leaks at leak sites. However, leaks tend to cluster since the gas pipes for neighborhoods tend to be laid at the same time and from the same material, thus becoming leakprone at the same time. It is likely that some SEIs are made up of more than one hole in one pipe under the ground. Thus some of the potential reasons for gas existing at the site a month after repair are:

- The repair crew repaired one hole in one pipe, and did not repair all holes in all pipes within the leak extent.

- The loosened dirt from the repair created a pathway for gas from a different but nearby leak to exit the ground.
- The repair jarred the aging pipe and caused further damage.

According to the gas companies' *Report to the Legislature 2020*²⁵, the estimated cost of repairing all 16,044 leaks left in the state at the end of 2020 was \$35 million. In the previous *Report to the Legislature 2019*²⁶, the estimated cost of repairing the 17,533 leaks left in the state at the end of 2019 was \$59 million. This means that learning how to increase the success rate of leak repair will be money well spent for both gas companies and customers. The least expensive time to repair a leak is the first time.

FluxBar Adoption and Use

Background



The FluxBar was invented during the pilot study through a collaboration of HEET, Eversource, Columbia Gas, Gas Safety Inc, Boston University Nathan Phillips and Millibar. The FluxBar is a utility-familiar tool that was redesigned to allow gas companies to compare the emissions of leaks in order to identify which were the largest just prior to repair. The FluxBar is not intended as a tool to identify SEIs as it requires a truck compressor and therefore can only be used by the leak repair crew just prior to repair. This repair crew use of the FluxBar on a significant number of SEIs could help result in data about SEIs, such as the pipe material, age or pressure that are correlated with SEIs, making identifying SEIs more efficient. It could also provide much needed directly measured flux data, potentially quantifying emissions reduced for carbon credits.

The FluxBar is inserted through a hole drilled through the road over the leak. It is connected to a truck compressor that blows air through the horizontal top of the tool. The flow of air, thanks to the Venturi effect²⁷, vacuums air up the standpipe at a steady three cubic feet per minute. A combustible gas indicator connected to the FluxBar head can then measure the percent of gas in that steady air flow from under the road surface, right over the leak. The gas readings over time are noted to calculate the steady state plateau. The result allows a consistent comparison of directly measured flow rate from one leak to the next.

In 2017, the large volume leak study found a correlation between FluxBar results and emissions, as measured using the chamber method which is a peer-reviewed method. Since

²⁵ Report to the Legislature on the Prevalence of Natural Gas Leaks in the Natural Gas System, 2020, D.P.U. 20-GLR-01

²⁶ Report to the Legislature on the Prevalence of Natural Gas Leaks in the Natural Gas System, 2019, D.P.U. 19-GLR-01

²⁷ https://en.wikipedia.org/wiki/Venturi_effect

emissions are also correlated with leak extent, there should be a relationship between leak extent and FluxBar results. Later in 2017, Columbia Gas captured a different leak extent through holes that were drilled through the road surface, instead of through “barholes” made using a handheld tool on the side of the road. We analyzed this second data set and found that while the distribution of the FluxBar steady state readings were similar to our initial data set, there was no correlation between the drill hole leak extent and the Fluxbar steady state. In 2018, we got no new FluxBar data and could not report any advances in understanding.

2019 Results

In 2019, adoption and use of the FluxBar increased and improved. Both Columbia Gas and Eversource used it during SEI repairs using the correct protocol. HEET attended some Eversource repairs to observe and help with its use. In 2020, National Grid purchased 8 more FluxBars and received training in its operation in September 2020.

While the FluxBar measures are a physical measure of flux at that location, we didn’t yet see the correlation expected between steady state flux calculations and leak extent measures. This may be related to the presence of multiple physical pipe leaks in a given leak extent, but more data is needed as we only had 10 leaks with FluxBar data to analyze. HEET continues to work with gas companies using the FluxBar to develop our understanding and potential future studies may include :

- Exploring the relationship further between FluxBar measurements, chamber method measurements and subsurface leak extent measurements
- Testing the zone of influence of FluxBar in different soils under different conditions
- Exploring drill hole leak extent protocol consistency and explore questions about dynamic changes in initial hour measurements

Shared Action Plan Year 2

HEET continues to work to meet our Shared Action Plan commitments, providing independent verification, analysis and reassessment. For Shared Action Plan year 2, we have already surveyed 100 verified SEIs and completed 300 miles of CRDS road surveying. Repair surveying has started and will continue through spring and summer. With the SEI regulations enacted, the Commonwealth has a plan to reduce its emissions by the equivalent of 4% of its greenhouse gas emission inventory within 3 more years.

Through this work, HEET continues its persistence and commitment to cutting carbon.

Appendices

Appendix 1 - Definitions and Acronyms

- **Barhole** : a hole made into the ground using a bangbar, into which a CGI is typically inserted to measure gas.
- **Barhole method** : The barhole method involves making a hole in the ground using a handheld bangbar and inserting a combustible gas indicator in the resulting barhole. Barhole reads are performed in different locations around a gas leak. Any leak with a barhole (sub-surface reading over 50% gas was considered an SEI leak).
- **Chamber method** : the scientific gold standard for leak emission measurement, using chambers of varying sizes to capture flux, or flow of methane over time, across the surface area of a leak.
- **Combustible Gas Indicator (“CGI”)** : a device used to detect flammable gas concentrations. The CGI is equipped with a 2-3 foot probe rod and hose assembly normally attached to an electronic unit that draws in an air sample using a built-in pump or by squeezing a rubber bulb.
- **Department of Public Utilities (DPU)** : In Massachusetts, the government agency charged with regulating the utility companies, with leadership appointed by the secretary of energy and environmental affairs.
- **EDF** - Environmental Defense Fund
- **Flame Ionization Unit (“FIU”)** : a device used to detect flammable gas concentrations. The FIU is comprised of a 2-3 foot probe rod and hose assembly normally attached to an electronic unit that draws in an air sample using a built-in pump which will provide a direct readout of gas in air concentrations.
- **Flux** : the rate of flow of a gas, such as methane, per unit area over time.
- **FluxBar** : a device used just prior to repair to capture and compare leak emissions
- **Grade 3 Gas Leak** : A leak classified as non-hazardous by utility workers at the time of detection and expected to remain non-hazardous..
- **Grade 3 SEI, or SEI** : a leak of Significant Environmental Impact. A grade 3 (non-hazardous) leak that emits enough gas to be in the top 10% of gas leaks in terms of emissions
- **GSEP** - Gas System Enhancement Plan is the 20 to 25 year plan of the gas companies to replace all the leakprone pipes under the ground in Massachusetts.
- **Large Volume Leaks (LVLs)** : large leaks in the distribution system, defined by a threshold leak extent measure of 2000 sq ft or more. Research so far indicates this is approximately 10% of all leaks, though further data may adjust the threshold. Also known as a leak of significant environmental impact (SEI).
- **Leak Extent** : surface area in which a gas company has detected positive CGI or FIU readings surrounded by an area of negative CGI or FIU readings.
- **Leakage Perimeter** : the process of creating a boundary of the leak extent. The leakage perimeter consists of subsurface inspection locations that can be monitored for changes in CGI readings. The leakage perimeter is established when 0% gas is obtained in two consecutive subsurface inspections (e.g., barholes, available openings).
- **Natural Gas** (or just ‘gas’ in this report) : a fossil fuel that, when processed and distributed as ‘pipe quality’, is roughly 97% methane.
- **SEI** - Significant Environmental Impact leak prioritized for repair in 2016 law passed in MA.
- **Subsurface Gas Detection** is the sampling of the subsurface atmosphere through barholes and/or available openings (e.g. cracks in the pavement, subsurface structures such as manhole covers, valve boxes, catch basins, etc.) with a combustible gas indicator (i.e. placing the indicator at least 6 inches into the barhole and/or available openings)
- **Super-emitting leak** : the top 7% of any population of leaks, emitting half of all the total gas by volume.
- **Surface Gas Detection** is a continuous sampling of the atmosphere at or near ground level for buried gas facilities and adjacent to above-ground gas facilities using an instrument approved for this type of survey on the appropriate sensitivity scale

Appendix 2 - Leak Extent Method

A Proposed Standardized Survey Method to Measure Leak Footprint

This protocol was created by all MA gas companies in Spring of 2018 in order to enact the leak extent method, adhering to the Shared Action Plan. (Note: definitions not included)

Suggested Method to Establish Leak Extent using CGI and Barhole

1. Establish the initial leakage perimeter of the suspected leakage area using a surface gas detection survey in accordance with appropriate Company standards or procedures.
2. If a gas indication is found, continue to establish the leakage perimeter by using the subsurface gas detection survey in accordance with appropriate Company standards or procedures.
3. Leak Extent is measured by multiplying the greatest width (perpendicular to the pipe) by the longest length (parallel to the pipe) to get total surface area. The width and length is established based on zero to zero readings.

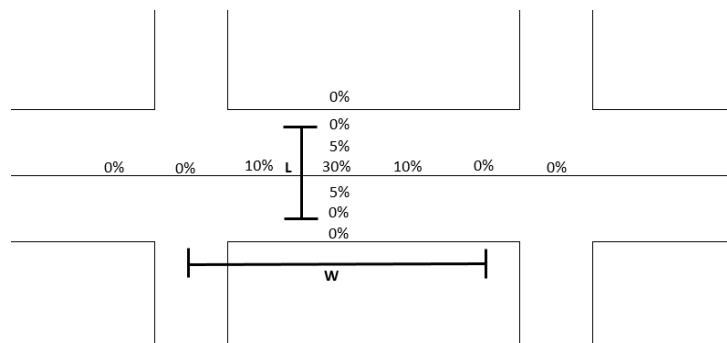


Figure 1 Capturing Leak Extent

Appendix 3 - Shared Action Plan

This is the Shared Action Plan agreed to by Columbia Gas, Eversource Gas, National Grid MA, and HEET, and supported by Mothers Out Front and the Gas Leaks Allies. The announcement of this agreement was at an MIT Summit in October of 2017. It was submitted to the Massachusetts Department of Public Utilities with a request that it be enacted statewide later the same month.

Identification

- Grade 3 LVL determined using leak extent as sole proxy method, at least for the first year.
- Leak footprint evaluated with a consistent and defined method across utilities (i.e. either with CGIs/FIs, barhole or drill holes). Method to be decided by utilities.
- Leaks over 10 years old not prioritized for repair unless it is LVL.

Repair

- Leaks > 10,000 sq. ft. fixed within 12 months of determination by leak repair or main replacement.
- When 2,000 to 10,000 square foot leaks are discovered and verified, we will endeavor to repair them within two years with the exception of inaccessible or challenging leaks which shall be repaired when access can be gained. If any 2,000 to 10,000 square feet leaks are on pipe that will be replaced through GSEP within five years, we will endeavor to eliminate the leak within three years.
- An LDC (a gas utility) may choose to cap its environmentally significant leak repairs in any one calendar year at 7% of its total Grade 3 leak inventory as indicated in the previous year's final quarterly leak report on file with the Department of Public Utilities.

Verification

- For first year, at minimum, a statistically significant randomized sample of Grade 3 LVL leak repairs are FluxBarred prior to repair. Method of verification to be reassessed annually. See below.

Reporting (Department of Public Utilities)

- On GSEP reports, the number of known LVL leaks on each pipe segment.
- On Annual Service Quality reports the leak address, leak footprint, date leak was reported, LVL classification date and repair date.

Reassessment

- Methods and results reassessed and adjusted annually for at least five years by a panel made up of utilities, HEET research team, and a mutually agreed-upon independent third party to provide recommendations to DPU.

Collaboration

- Initial Year Collaboration to support the transition. Leak addresses, reports and repair dates of all high emitters shared with HEET so we can randomly survey 100 leaks to ensure consistency across utilities. FluxBar data forms shared with HEET for the first year so we can provide any needed assistance. Fluxbar results will allow for apples-to-apples comparison between leaks, progress to be benchmarked and further learning to allow for more efficient allocation of resources.

Appendix 4 - Applied Economics Calculation Additional Information

Calculating the cost of repairs per leak.

Measure		Source
Annual MA total gas consumption (therms)	4,660,931,310	EIA, MA total annual natural gas consumption, 2017 http://www.eia.gov/dnav/ng/ng_cons_sum_dc_u_SMA_a.htm
Annual share lost in transmission	2.7%	McKain K, et al http://www.pnas.org/content/112/7/1941.full
Annual total gas lost in transmission (therms)	125,845,145	(Share X consumption)
Annual share lost in distribution system	30.0%	Senior authors on McKain K. et al paper (Harvard Prof. Wofsy & B.U. Prof. Phillips) assume between 30% and 50%; personal communication
Est. Annual gas lost in distribution (therms)	37,753,544	(Transmission loss X share lost)
Gas cost (per therm)	\$0.30	Marginal cost of gas/ million btu: EIA Henry Hub Gas Spot Price, 2017 average ; EIA conversion factors: https://www.eia.gov/tools/faqs/faq.php?id=45&t=8
Est. Annual total cost of gas lost in distribution	\$11,272,579	(Gas cost X gas lost)
MA total number of reported leaks	17,810	DPU report to legislature December 2017 https://eeonline.eea.state.ma.us/EEA/FileService/FileService.Api/file/FileRoom/9171108
MA utility reported estimates of leak repair	\$70,085,286	DPU report to legislature December 2017: https://eeonline.eea.state.ma.us/EEA/FileService/FileService.Api/file/FileRoom/9171108
Cost of repair/leak (calculated)	\$3,935	(Total cost / leaks)

Appendix 5 - CRDS Analysis Methods

- The Picarro generated KML data for the survey route was compiled and plotted in Google Earth
- Towns were identified through which the CRDS route went
- Unrepaired leaks from the Annual Service Quality Reports (ASQR) for 2019 were cleaned and geocoded, correcting reporting errors and providing accurate mapping and then overlaid onto the CRDS route data in Google Earth
- ASQR unrepaired leaks on the CRDS route were summed up for each utility and town on the route
- Correspondences between CRDS elevated methane readings and ASQR unrepaired leaks were summed up for each utility and town on the route
- Correspondence rate for each utility was calculated as : $\text{sum of on-route correspondences across all towns} \div \text{sum of on-route ASQR unrepaired leaks across all towns}$
- Elevated CRDS readings that didn't correspond with ASQR 2019 unrepaired leaks were counted as elevated methane locations (potential leaks) and summed up.
- **Notes**
 - There was a month or less of time between the CRDS data and the ASQR report (ie fairly fresh data)
 - Correspondences were visually tested for in Google Earth, not programmatically
 - Even the smallest of methane elevations above baseline were counted as a potential leak detection
 - Utilities report leak locations using addresses, so a certain amount of experience-based latitude/buffer around the leaks was allowed when matching elevated CH₄ readings with leak location
 - Due to resources and time, we were not able to survey with the leak extent method all potentially new SEIs indicated by the Picarro readings

Appendix 6 - PHMSA Funded SEI Evolution Project

In 2019, HEET was awarded a PHMSA technical assistance grant to explore SEI grade evolution and safety. This more extensive study followed 100 verified SEIs across 4 seasons. The final PHMSA report can be found [here](#).

This project aimed to learn more about the new G3SEI leak classification and to provide education to the public, first responders and municipalities about gas leak classifications and their repair prioritization.

Project Goals

1. Assess the safety profile of G3SEI leaks by measuring and analyzing data about the following:
 - a. The rate of evolution of G3SEIs into Grade 2 and Grade 1 leaks, to help gas companies improve prioritization of leak repairs
 - b. The pipe material, age and pressure that G3SEI leaks are occurring on, to determine possible predictors of G3SEI locations
 - c. The repair success rate of G3SEIs compared to other grades, to learn whether repairs of G3SEIs are more successful or challenging
2. Educate the public, municipalities, and first responders about leak classification and prioritization

Project Scope

The scope involved a random sampling of 100 G3SEIs on distribution mains within each of the territories of Massachusetts' three largest gas distribution companies, National Grid, Eversource and Columbia Gas (representing ~95% of all MA gas customers). These companies had agreed to provide G3SEI locations that they have identified in 2019 to HEET for this project. Their territories are concentrated in eastern Massachusetts, which also contains the majority of the population of the state. This region has a diversity of distribution pipe materials including plastic, steel and iron, and a wide range of operating pressures. This diversity provided an excellent and varied sample for this study. The project also included a high precision leak survey using a cavity ringdown spectrometer surveying system (CRDS) applied to 300 miles of roads in the same areas where the G3SEIs were identified by the gas companies. This road survey data was used to verify that G3SEIs are getting reliably located by the gas companies, and may ultimately help improve how G3SEIs are located. Educational scope covered the Massachusetts public, first responders and municipalities in the greater Boston area.

Key Project Findings at a Glance

For the G3SEIs studied in this project :

- Their size was not a predictor of growth potential and/or variability
- Their grades evolved (got worse) at a similar rate to Grade 3 non-G3SEIs, about 13%

- They were repaired successfully only 36% of the time
- G3SEIs were found predominantly on low pressure 6" cast iron pipe installed before 1930 and intermediate pressure 2" coated steel pipe installed after 1930
- The cavity ringdown spectrometer (CRDS) identified additional new potential leaks

Key Recommendations

Our finding that 13% of Grade 3 leaks across both regular and G3SEI categories did evolve grade in the course of a year calls into question the definition of Grade 3 leaks being 'non-hazardous' and raises questions regarding leak classification. To ensure such grade evolutions are caught promptly, we recommend assessing the need for standardizing Grade 3 resurvey rates and potentially enhancing [49 CFR § 192.173 - Distribution systems: Leakage surveys](#).

Our finding that repairs were only fully successful 36% of the time was concerning. This low rate may be due to multiple leaks existing at those leak locations, with only a subset being identified and repaired. Improving surveying protocols to better find these multiple constituent leaks may improve repair and safety outcomes and we recommend considering enhancing [49 CFR § 192.173 - Distribution systems: Leakage surveys](#). Additionally, further study of leak repair failures to increase success rate may be useful, given the cost efficacy of repairs vs. pipe replacement.

Our finding of G3SEIs occurring most commonly on two categories of leak prone pipe can be used by gas utilities to more efficiently identify and prioritize G3SEI leaks for repair. Given an initial Massachusetts gas utility study²⁸ indicated that leaks with higher leak flux were on pipes with higher gas pressure, which seems intuitive, we further recommend the prioritization of the intermediate steel category over the low pressure cast iron category. In order for PHMSA to act on this, we suggest further study and data collection of G3SEI flux (see [Recommended further study and research](#)).

Finally, HEET urgently recommends that all gas utilities around the country follow the lead of Eversource Gas, National Grid Gas, the former Columbia Gas MA, and the Commonwealth of Massachusetts in prioritizing the identification and repair of G3SEIs. This is an effective method for cities and municipalities to accelerate decarbonization safely and cost-effectively, while moving towards their greenhouse gas reduction goals as quickly as possible.

28 Magavi, Z., Ackley, R., Hendrick, M., Salgado, E., Schulman, A., Phillips, N., "[A Method of Identifying Large Volume Leaks in Natural Gas Distribution Systems](#)"

Appendix 7 - Calculating The Greenhouse Gas Emissions of SEIs

Calculating the Greenhouse Gas Emissions ²⁹	
Total gas consumption MA statewide 2019 Source: EIA, https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMA_a.htm)	433.8 billion cubic feet
Rate of gas leaked annually into atmosphere in Greater Boston ³⁰	2.5%
Total MA statewide annual leaked gas (assuming leak rate applies statewide)	10.8 billion cubic feet
20 year timeframe of methane's impact on the climate - its global warming potential (GWP ₂₀) (Source: IPCC)	86
Total annual leaked gas CO2 equivalent (million metric tonnes CO2 equivalent)	18.9 MMCO2e
Most recently available 2011 MA Greenhouse Gas Inventory ³¹	78.6 MMCO2e
Total MA statewide annual leaked gas, as a proportion of the MA GHG inventory	24%
Total MA statewide annual leaked gas from distribution infrastructure (conservatively estimated as 30% of all leaked gas) as a proportion of the MA GHG inventory	7.2%
Half of the distribution infrastructure leaked gas attributed to super-emitter leaks	3.6%, or, 2.8 MMCO2e of MA GHG
MA GHG 2017 emissions for commercial sector ³²	7.3 MMCO2e
Super-emitter leaks as a percentage of commercial sector	39%

²⁹ This uses the same calculation approach as described [Dr Phillips blog article](#)

³⁰ Page 7, https://www.mass.gov/doc/stakeholder-comments-received/download?_ga=2.59952174.2043028726.1617304058-75415503.1617304058

³¹ Source: MassDEP <https://www.mass.gov/files/documents/2016/11/xv/gwsa-update-16.pdf>

³² [Appendix C: Massachusetts Annual Greenhouse Gas Emissions Inventory: 1990-2017, with Partial 2018 Data](#)

Appendix 8 - Acknowledgements

The stakeholder ecosystem that supported this work was vast and ever changing. It is our intent to acknowledge all. Any names or organizations overlooked are unintentional. Our sincere thanks to all.

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PARTICIPATING ORGANIZATIONS: Eversource Gas, Columbia Gas MA, National Grid Gas, Brian Ferri of Millibar Inc., MAPC, and grassroots support and action from Gas Leaks Allies and Mothers Out Front volunteers and teams.

GAS LEAKS ALLIES: Arise for Social Justice, Boston Climate Action Network, Boston Park Advocates, Brookline Green Space Alliance, Clean Water Action, Climate Action Now—Western Massachusetts, Climate Reality Project—Boston Chapter, Climate Action Business Association (CABA), Community Labor United, Conservation Law Foundation, Emerald Necklace Conservancy, Friends of the Public Garden, Garden Club of the Back Bay, Gas Safety USA, Greater Boston Physicians for Social Responsibility, Green Committee, Neighborhood Association of Back Bay, HEET, Longmeadow Pipeline Awareness Group, Mothers Out Front, SAFE—Salem Alliance for the Environment, Sierra Club—Massachusetts Chapter, Springfield Climate Justice Coalition, Toxics Action Center, 2degrees@greenneighbors.earth, 350MA, Dr. Margaret Cherne-Hendrick, Fresh Energy, Dr. Nathan Phillips, Boston University